CLAUDIU SERGIU HÂRTOPANU[1]

ANALYSIS OF UNCERTAINTY IN IMPLEMENTING A FES EXOSKELETON SYSTEM USING ELEMENTARY FUZZY NUMBERS

Abstract: *We intend to build a system for the rehabilitation of the upper limb in people who have suffered a stroke. This study shows an analysis of the uncertainty in developing a FES-Exoskeleton system using elementary fuzzy numbers. Uncertainty is a term that includes both negative and positive aspects, and that is why we can differentiate it from the risk.*

Keywords: uncertainty, analysis, fuzzy, numbers, methods.

1. Introduction

With the advancement of technology, the state of uncertainty caused by natural processes and natural events can be avoided, and major investments in the field of robotics have been made. If we reduce the nature of the uncertainty to a feeling (Hofstede G. p. 133) acquired as a result of a personal experience or of the experience of a group to which it belongs, its size directly and indirectly influences the performance of the economy, and we can no longer know exactly what will be the possibilities to achieve the factors for the patient's recovery.

The method used by the fuzzy systems directly or indirectly involve the implementation of a set of heuristic rules in a system. We must consider that when we apply a method, it will not avoid certain answers, such as the extreme ones.

Nowadays we can consider uncertainty as a norm for the processes that are taking place in economy, because the information needed by the economic operators to achieve the best results under the given conditions are not available, and when these are obtained, they are partially affected by errors or incomplete (Prunea P., p. 19).

In the decision-making phase uncertainty refers to the preference of choosing a solution as good as possible. The decisions in uncertainty are chosen using several techniques. The most commonly used techniques are: the pessimistic or the prudence technique (Abraham Wald), the optimist, the optimality technique (Leonid Hurwicz),

[1] PhD Fellow, POSDRU/159/1.5/S/133675 Project, "Gh. Zane" Institute of Economic and Social Research, Romanian Academy – Iaşi Branch. "Gheorghe Asachi" Technical University of Iași, Romania.

the technique of balance or equiprobability (Bayes-Laplace) and the minimisation of regrets (Leonard I. Savage). In this study we analyze the choice of decision using the methods mentioned above helping us with the elementary fuzzy numbers corresponding to each technique.

What we have proposed is to develop a system that combines an artificial exoskeleton with electrical stimulation, for the recovery of the persons with motor disabilities. The challenge of this project lies in choosing suitable motors for the drive of the exoscheleton. These motors should be small in size and develop a force enough to achieve the flexion and extension of a finger. We have three types of motors that we can use in this project, namely, linear motors, and step by step motors. These types of motors will be at the base of the scenarios taken into account for the study below in order to establish the decisions in cases of uncertainty.

2. Analysis of uncertainty using elementary fuzzy numbers

Prior to the completion of this prototype we need to identify uncertainties that may occur in the system's implementation. There were two teams for the evaluation and finding of uncertainties. A team of five specialists from the department of research and development and another team of three experts in management and marketing. The scenarios' rating was made on a scale of 1 to 5 (1 – the lowest result, 5 – the highest result). Also, for every uncertainty we established its importance for the project.

The following possible scenarios in the case of reduction risks, delay and exceeding of funding, the following uncertainties may occur at the implementation of this system, that have been drawn up by the team of experts in marketing and management.

We will consider three scenarios, namely the use of linear motors, of servomotors and of step by step motors. For each scenario separately we shall study the uncertainties set out by the two assessment teams, i.e. *the uncertainty of the personnel* referring to the personnel which is involved both directly and indirectly in the project. In this case it may appear the uncertainty of finding qualified personnel, the uncertainty of personnel fluctuation and the uncertainty of the personnel's skills. To avoid the risk of finding qualified personnel, the search will begin before the starting of the project, in order to have enough time to study the skills of each employee. Personnel fluctuation can occur due to both the payroll and the stress at work. In the case of uncertainty of the costs of acquisition and processing of materials, we will conclude contracts to establish the prices before beginning the development of the system, to avoid the risks regarding the acquisition costs. However the costs' uncertainty will remain and it may be caused by the change in the political regime, changes in taxes.

In the case of the three scenarios, the *failures uncertainty* may appear on the following systems:

– sensorial;

– of actuation;

– of electrical stimulation;

– of feeding.

These failures may occur both because of the cost but also because of the unqualified personnel, or because of their lack of attention.

Time uncertainty regarding the supply of:

– parts;

– documentation.

This uncertainty of supply time can be caused both by the financial risks and by those related to stock and transport provided by the supplier.

1^st^ CASE SCENARIO

In this scenario we will describe the uncertainties that we may face while using linear motors.

The linear motors serving the project's requirements (size, strength, power supply) are available from a single supplier, in Canada, and this will make more difficult to find the qualified personnel to work with this type of engines. Due to the distance and having a single supplier, the uncertainty of the costs and of the delivery time appears. The advantages of using these motors are the small size and a decrease in the extensive use of the system (Sergiu Hartopanu *et al.*, 2015).

Just like any electronic component, the engines have a longer lifespan than the servomotors and the step by step motors, and so they have a lower risk of failure of the driving system or any other system that is part of the project.

In case of motor failure, it can occur the risk of damaging other components if it is not replaced by a qualified person.

2^nd^ CASE SCENARIO

The advantage of using servomotors consists in the easier finding of qualified personnel, and at lower cost, but the major disadvantages are the dimensions of the motors, the developed forces and the frequent failures that can occur due to their construction, namely the use of plastics that deteriorates very quickly (S. Hartopanu *et al.*, 2013).

When using this type of motors, extra expenses occur due to higher dimensions, as they need a special fixture. The advantages of servomotors and linear motors consist in a good movement precision. Servomotors are very often used in robotics.

3rd CASE SCENARIO

The stepper motor is a synchronous motor because the rotation speed, which depends directly on the feeding pulse frequency, expressed by the number of steps made during one unit of time.

During the use of these motors for our recovery system is much easier to find qualified staff, because they are very often used in industry, as well as for automation and many household electronic devices.

The major disadvantages of these motors are size and accuracy at higher rotation speeds.

In the following table we have the ratings from 1 to 5 depending on the importance of the two teams' evaluations for the three scenarios:

Table 1

Scenarios of possible uncertainties when using linear motors

Uncertainty	**uncertainty**	**Team 1**		**Team 2**	
		Note	**importance**	**note**	**importance**
Uncertainty regarding the personnel	Qualified personnel	**5**	**50%**	4	45%
	Personnel fluctuation	**4**	**25%**	3	25%
	Personnel skills	**4**	**25%**	4	30%
Uncertainty regarding the costs	of acquisition of the parts	**4**	**60%**	5	45%
	of processing of materials	**3**	**40%**	5	55%
Uncertainties of failures	on the sensorial system	**3**	**45%**	2	30%
	on the actuation system;	**1**	**15%**	2	30%
	on the electrical simulation system;	**2**	**15%**	3	30%
	on the feeding system;	**3**	**20%**	1	10%
Uncertainty of the time to supply	the parts	**4**	**45%**	5	40%
	the documentation	**2**	**55%**	3	60%

Table 2

Scenarios of possible uncertainties when using servomotors

Uncertainty	**Uncertainty**	**Team 1**		**Team 2**	
		Note	**importance**	**note**	**importance**
Uncertainty regarding the personnel	Qualified personnel	**2**	**30%**	3	40%
	Personnel fluctuation	**2**	**30%**	3	50%
	Personnel skills	**1**	**40%**	2	10%
Uncertainty regarding the costs	of acquisition of the parts	**2**	**60%**	3	70%
	of processing of materials	**4**	**40%**	4	30%
Uncertainties of failures	on the sensorial system	**4**	**40%**	3	40%
	on the actuation system;	**5**	**30%**	3	20%
	on the electrical simulation system;	**3**	**20%**	3	20%
	on the feeding system;	**4**	**10%**	3	20%
Uncertainty of the time to supply	the parts	**2**	**50%**	3	40%
	the documentation	**1**	**50%**	2	60%

Table 3

Scenarios of possible uncertainties when using stepper motors

Uncertainty	**Uncertainty**	**Team 1**		**Team 2**	
		note	**importance**	**note**	**importance**
Uncertainty regarding the personnel	Qualified personnel	**3**	**30%**	4	40%
	Personnel fluctuation	**3**	**50%**	3	50%
	Personnel skills	**4**	**20%**	4	10%
Uncertainty regarding the costs	of acquisition of the parts	**3**	**65%**	3	55%
	of processing of materials	**3**	**35%**	3	45%
Uncertainties of failures	on the sensorial system	**4**	**35%**	3	20%
	on the actuation system;	**5**	**25%**	4	30%
	on the electrical simulation system;	**4**	**30%**	3	30%
	on the feeding system;	**2**	**10%**	1	20%
Uncertainty of the time to supply	the parts	**3**	**50%**	3	60%
	the documentation	**4**	**50%**	4	40%

In order to determine the triangular fuzzy numbers we need the weights for each uncertainty, that are calculated below:

Table 4

Consequences matrix

	Weights								
			I1		**I2**		**I3**		**I4**
S1		**0,475**	**(4; 5)**	**0,525**	**(4; 5)**	0,400	(2; 3)	0,425	(4; 5)
		0,250	(3; 4)	0,475	(3; 5)	0,225	(1; 2)	0,575	(2; 3)
		0,375	(4; 4)			0,225	(2; 3)		
						0,150	(1; 3)		
S2		0.35	(2; 3)	0.65	(2; 3)	0.40	(4; 3)	0.45	(2; 3)
		0.40	(2; 3)	0.35	(4; 4)	0.25	(5; 3)	0.55	(1; 2)
		0.25	(1; 2)			0.20	(3; 3)		
						0.15	(4; 3)		
S3		0.35	(3;4)	0.60	(3; 3)	0,275	(4;3)	0.55	(3; 3)
		0.50	(3; 3)	0.40	(3; 3)	0,275	(5;4)	0.45	(4; 4)
		0.15	(4; 4)			0,300	(4;3)		
						0,150	(2;1)		

S1, I1: 0.475 × (4; 5) + 0.250 × (3; 4) + 0.375 × (4;4) = (1.9 + 0.75 + 1.5; 2.375 + 1 + 1.5) = (4.15; 4.875)

S1, I2: 0.525 × (4; 5) + 0.475 × (3; 5) = (2.1 + 1.425; 2.625 + 2.375) = (3.525;5)

.

.

.

S3, I4: 0.55 × (3; 3) + 0.45 × (4; 4) = (1.65 + 1.8; 1.65 + 1.8) = (3.45; 3.45)

After processing the information for the three scenarios the following consequences matrix was obtained:

Scenario	**I1**	**I2**	**I3**	**I4**
S1	[4.15; 4.875]	[3.525; 5]	[1.625; 2,775]	[1,955; 385]
S2	[1.75; 275]	[27; 3.35]	[3; 405]	[1.45; 245]
S3	[315; 3.5]	[3; 3]	[2.975; 3,975]	[3.45; 345]

We will further use fuzzy numbers for a ranking of the scenarios, according to the Savage, Abraham Wald and maxi-max methods. In our case we have m = 4 (columns/criteria) and n = 3 (lines/scenarios/decision-making variants).

Matrix of results (initial matrix)

	V1	V2	V3
C1	4.15 4.875	1.75 2.75	3.15 3.5
	4.512	2.25	3.325
C2	3.525 5	2.7 3.35	3 3
	4.262	3.025	3
C3	1.625 2.775	3 4.05	2.975 3.975
	2.2	3.525	3.475
C4	1.955 3.85	1.45 2.45	3.45 3.45
	2.902	1.95	3.45

In the table above we have the extremities of the fuzzy number and the centre of gravity which represents the arithmetic average between extremities.

The utilities of the results are obtained as follows:

$$\tilde{R}_1^{\max} = \max_{1 \le j \le n} \tilde{R}_{ij} = \max[(4.15, 4.875)_{4.512};\ (1.75,\ 2.75)_{2.25};\ (3.15,\ 3.5)_{3.325}] = (4.15,\ 4.875)_{4.512}$$

$$\tilde{R}_1^{\min} = \min_{1 \le j \le n} \tilde{R}_{ij} = \min[(4.15, 4.875)_{4.512};\ (1.75,\ 2.75)_{2.25};\ (3.15,\ 3.5)_{3.325}] = (1.75,\ 2.75)_{2.25}$$

$$\tilde{u}_{11} = \frac{\tilde{R}_1^{\max} - \tilde{R}_{11}}{\tilde{R}_1^{\max} - \tilde{R}_1^{\min}} = 0$$

The maximum number is the rectangle fuzzy number with the higher center of gravity.

Among the best known and used decision criteria to identify the optimum action direction we include:

– the pessimistic criterion (Abraham-Wald)

$$V^{*} = \max_{i} \min_{j} \left(\tilde{R}_{ij} \right)$$

– optimistic criterion (maxi max)

$$V^{*} = \min_{i} \max_{j} (\tilde{R}_{ij})$$

– the criterion of minimum regrets – minimax (Savage)

$$\tilde{A}_{ij} = \max_{i} (\tilde{R}_{ij}) - \tilde{R}_{ij}$$

$$V^{*} = \min_{i} \max_{j} (\tilde{A}_{ij})$$

Maxi-Max	$\tilde{M}_{j} = \max_{1 \le i \le m} \tilde{u}_{ij}$
Wald	$\tilde{W}_{j} = \min_{1 \le i \le m} \tilde{u}_{ij}$

Operation of the normalization of the lines (***linear interpolar,*** at the interval [0, 1]), it can be achieved simultaneously for all the 2 · 3 = 6 (real) components on each line.

For the first line:

$$R_1^{\min} = \min(4.15;\ 4.875;\ 1.75;\ 2.75;\ 3.15;\ 3.75) = 1.75$$

$$R_1^{\max} = \max(4.15;\ 4.875;\ 1.75;\ 2.75;\ 3.15;\ 3.75) = 4.875$$

$$R_{1x} \to \frac{R_{1x} - R_1^{\min}}{R_1^{\max} - R_1^{\min}} = \frac{R_{1x} - 1.75}{4.875 - 1.75} = \frac{R_{1x} - 1.75}{3.125},$$

$$4.15 \to \frac{4.15 - 1.75}{3.125} = \frac{2.4}{3.125} \approx 0.768,$$

$$4.875 \to \frac{4.875 - 1.75}{3.125} = \frac{3.125}{3.125} \approx 1,\ \ldots,\ 3.45 \to \frac{4.875 - 1.75}{3.125} = \frac{3.125}{3.125} = 1.$$

The other 5 lines are calculated similarly. The matrix of utilities is as follows:

Matrix of utilities

	V1	V2	V3
C1	0,768 1	0 0.32	0,448 0.56
	0,884	0.16	0,504
C2	0,369 1	0 0,282	0.13 0.13
	0,684	0,141	0.13
C3	0 0,474	0,567 1	0,556 0,969
	0,237	0,783	0,762
C4	0,206 1	0 0,416	0,833 0,833
	0,603	0,208	0,833

Weighted utilities shall be obtained by multiplication with the fixed weight $\frac{1}{m} = \frac{1}{4} = 0.25$:

$$\tilde{u}_{11} \leftarrow \tilde{u}_{11} = 0.25 \cdot (0.768,\ 1)_{0.884} = (0.25 \cdot 0.768,\ 0.25 \cdot\ 1)_{0.884 \cdot 0.25} =$$
$$\approx (0.192,\ 0.25)_{0.221}\ ,\ \dots,$$
$$\tilde{u}_{43} \leftarrow \tilde{u}_{43} = 0.25 \cdot (0.883,\ 0.883)_{0.883} \approx (0.22,\ 0.22)_{0.22}\ .$$

Matrix of weighted utilities

	V1	V2	V3
C1	0,192	0	0,112
	0.25	0.08	0.14
	0,221	0.04	0,126
C2	0,092	0	0,032
	0.25	0.07	0.32
	0,171	0,035	0,032
C3	0	0,141	0,139
	0,118	0.25	0,242
	0,059	0,195	0.19
C4	0,051	0	0,022
	0.25	0,104	0,022
	0.15	0,052	0,022

a) *The maxi-max method*

The specific indicator $\tilde{M}_j\ , \mathrm{j} = \overline{1,3}$ is calculated as below (the maximum fuzzy numbers are chosen in the columns of the previous table):

$$\tilde{M}_1 = \max_{1 \le i \le 6}\ \tilde{\mathrm{u}}_{\mathrm{i}1} = \max(\tilde{u}_{11}, \tilde{u}_{21}, \tilde{u}_{31}, \tilde{u}_{41}, \tilde{u}_{51}, \tilde{u}_{61}) = \tilde{u}_{11} = (0.037, 0.062)_{0.05}\ \dots$$

The fuzzy number $\tilde{\mathrm{u}}_{11}$ was chosen because it has the largest center of gravity.

The 3 indicator values are listed in the first row in the following table.

The fuzzy values of the specific indicators of the 2 ranking methods (Maxi-max and Wald)

	V$_1$	**V$_2$**	**V$_3$**
$\tilde{M}_j$	0.192	0.141	0.139
	0.25	0.25	0.242
	0.221	0.195	0.19
$\tilde{W}_j$	0	0	0.022
	0.118	0.07	0.022
	0.059	0.035	0.022

By ordering in descending direction the centres of gravity of the specific indicator and the variants, we have the ranking by the maxi-max method:

$$0.221 > 0.195 > 0.190$$

$$\boxed{\mathbf{V}_1 \succ \mathbf{V}_2 \succ \mathbf{V}_3}$$

b) ***Wald's method***

The specific indicator $W_j,\ j=\overline{1,3}$ is calculated as follows (minimum fuzzy numbers in columns):

$$\tilde{W}_1 = \min_{1\le i\le 6} \tilde{u}_{i1} = \min(\tilde{u}_{11},\tilde{u}_{21},\tilde{u}_{31},\tilde{u}_{41},\tilde{u}_{51},\tilde{u}_{61}) = \tilde{u}_{21} = (0.000, 0.015)_{0.008}\ \ldots$$

The 3 indicator values are listed in the 2nd row of the previous table.

By ordering in descending direction the centres of gravity of the specific indicator and the variants, we have the ranking by the maxi-max method:

$$0.059 > 0.035 > 0.022$$

$$\boxed{\mathbf{V}_1 \succ \mathbf{V}_2 \succ \mathbf{V}_3}$$

4. Conclusions

We had in mind the carrying out a study for the decision making in case of uncertainty in making a system that combines the electrical stimulation with a functional artificial exoskeleton, a system used for the recovery of the persons who have suffered a stroke and that have an outstanding potential in terms of the motor function of the wrist.

Three cases have been developed and commented for this study, namely the use of three types of hydraulic motors for the actuation of the exoskeleton (linear motors, servomotors and stepper motors).

In the decision-making phase uncertainty refers to the preference of choosing a solution as good as possible. The decisions in uncertainty are chosen using several techniques. The techniques used were the pessimistic or the prudence technique (Abraham Wald) and maxi-max.

Therefore, the method of innovation proposed within our system is described and proposed in the first scenario, and it assumes the achievement of the system with linear motors. The duration of operation of the device will be longer, without problems regarding the electrical part.

The present analysis shows that the achievement of the system using linear motors has considerable advantages that can justify the investment required.

Acknowledgments. This paper is supported by the Sectorial Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Government under the contract number POSDRU/159/1.5/133675.

5. Bibliography

Hofstede G., "Managementul structurilor multiculturale", *Management of multicultural structures*, Editura Economica, Bucharest, 1996, p. 133.

Prunea P. "Riscul in activitatea economica. Ipostaze. Factori. Modalitati de reducere", *Risk in economic activity. Aspects. Factors. Reduction modes*, Editura Economica, Bucuresti, 2003, p. 19.

Hartopanu S., Poboroniuc M. S., Serea F., Irimia D.C., Livint G., Design of a Hybrid FES-Mechanical Intelligent Haptic Robotic Glove, in Proceedings of the 17th International Conference on Systems Theory, Control and computing ICSTCC2013, Sinaia, Romania, 11–13 October 2013, pp. 687–692, ISBN 978-1-4799-2228-4, ISBN 978-1-4799-2227-7, IEEE catalog Number CFP1336P-CDR, DOI: 10.1109/ICSTCC.2013.6689040. indexed Web of Science Thomson Reuters &IEEE Xplore.

Hartopanu S., Poboroniuc M. S Serea F., Irimia D.C., Livint G. New Issues on FES and Robotic Glove Device to Improve the Hand Rehabilitation in Stroke Patients, 6th International Conference on Modern Power System 2015, At Cluj Napoca, ISSN 1841-3323, BDI indexed.

Ovidiu Gherasim, Mathematics of uncertainty, Performantica, Iasi, 2008.

Mihaele (Ghindeanu), *Colhon Fuzzy Logic Elements*, Craiova, 2012.